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(54) **SYSTEMS AND METHODS FOR PHYSICAL CHANNEL REPETITION FOR LOW LATENCY COMMUNICATION**

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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2016/0142981 A1* 5/2016 YI H04W 52/242
455/522
2016/0211949 A1* 7/2016 You H04W 4/70
2016/0269160 A1* 9/2016 Noh H04L 5/0048
2017/0019216 A1* 1/2017 Li H04L 1/08
2017/0374640 A1* 12/2017 Kim G01S 5/0226
2018/0092085 A1* 3/2018 Shaheen H04W 72/048

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(Continued)

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(57) **ABSTRACT**

(51) **Int. Cl.**

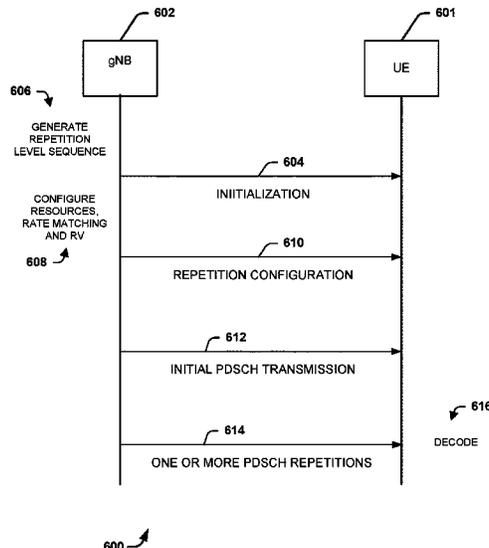
H04L 1/08 (2006.01)
H04W 72/04 (2009.01)
H04W 76/27 (2018.01)
H04L 27/00 (2006.01)
H04L 1/00 (2006.01)
H04L 5/00 (2006.01)
H04L 1/16 (2006.01)

An apparatus is configured for a next Generation NodeB (gNB). The apparatus comprises baseband circuitry and/or application circuitry which includes a radio frequency (RF) interface and one or more processors. The one or more processors are configured to determine a transmission mode for a user equipment (UE) device; dynamically determine a repetition level sequence for a physical downlink shared channel (PDSCH) based on a transmission time interval (TTI) and the transmission mode; generate repetition level signaling for the determined repetition level sequence; and provide the generated repetition level signaling to the RF interface for transmission to the UE device.

(52) **U.S. Cl.**

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7 Claims, 8 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

2019/0246378 A1* 8/2019 Islam H04W 72/12
2019/0342030 A1* 11/2019 Hosseini H04W 72/1289
2019/0342058 A1* 11/2019 Kwak H04W 72/1273
2020/0195408 A1* 6/2020 Steiner H04L 1/0061

* cited by examiner

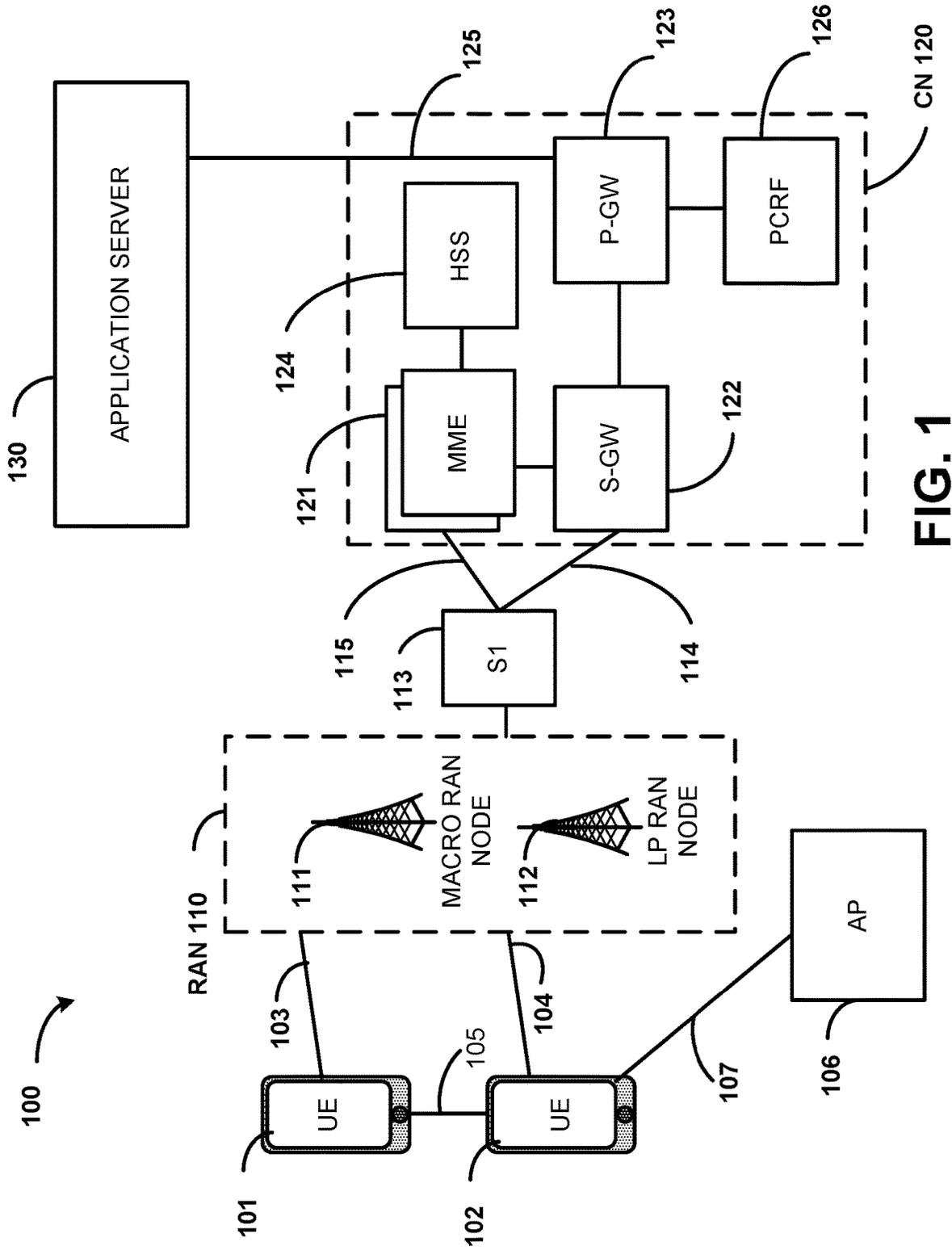


FIG. 1

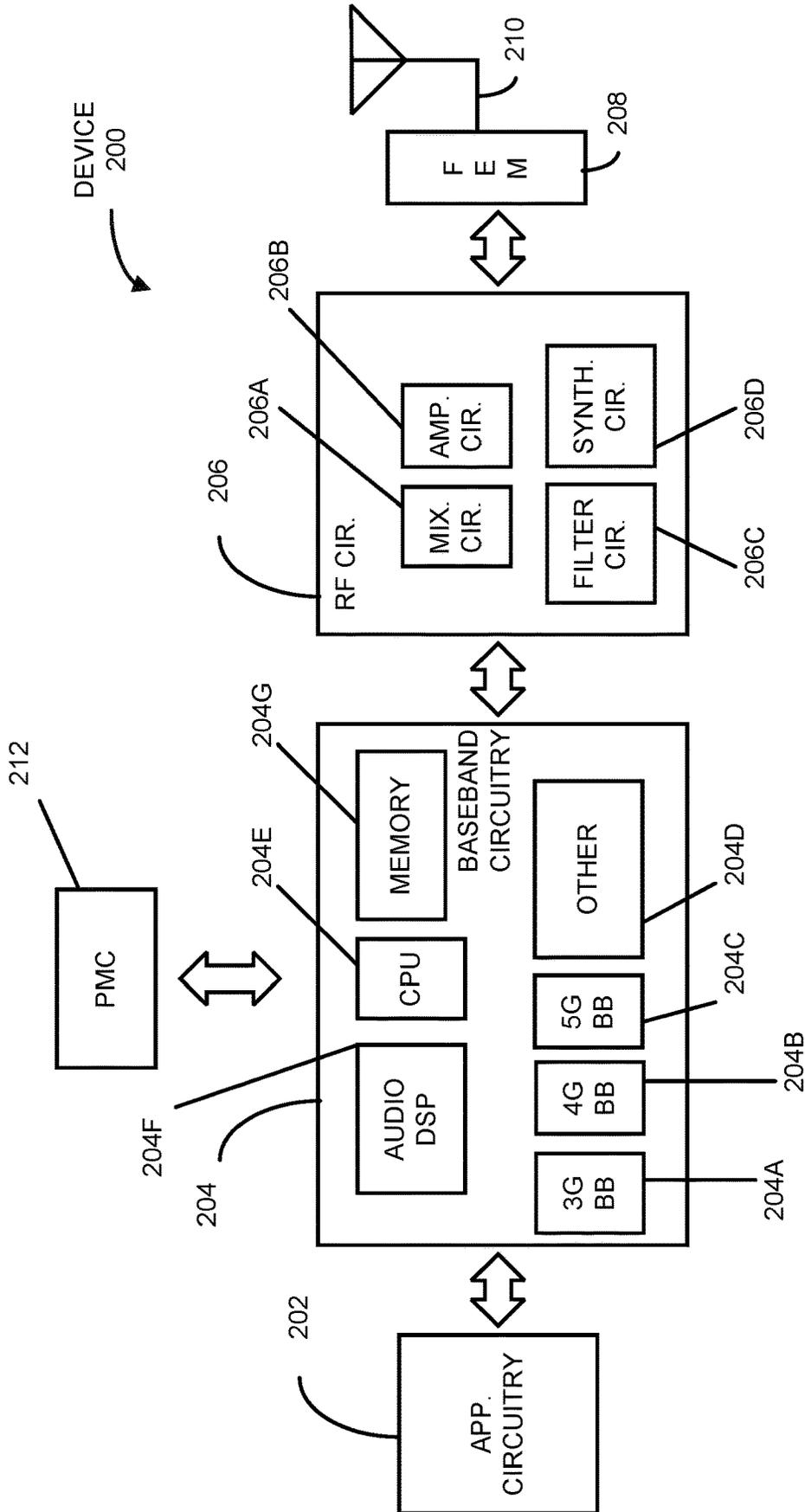


FIG. 2

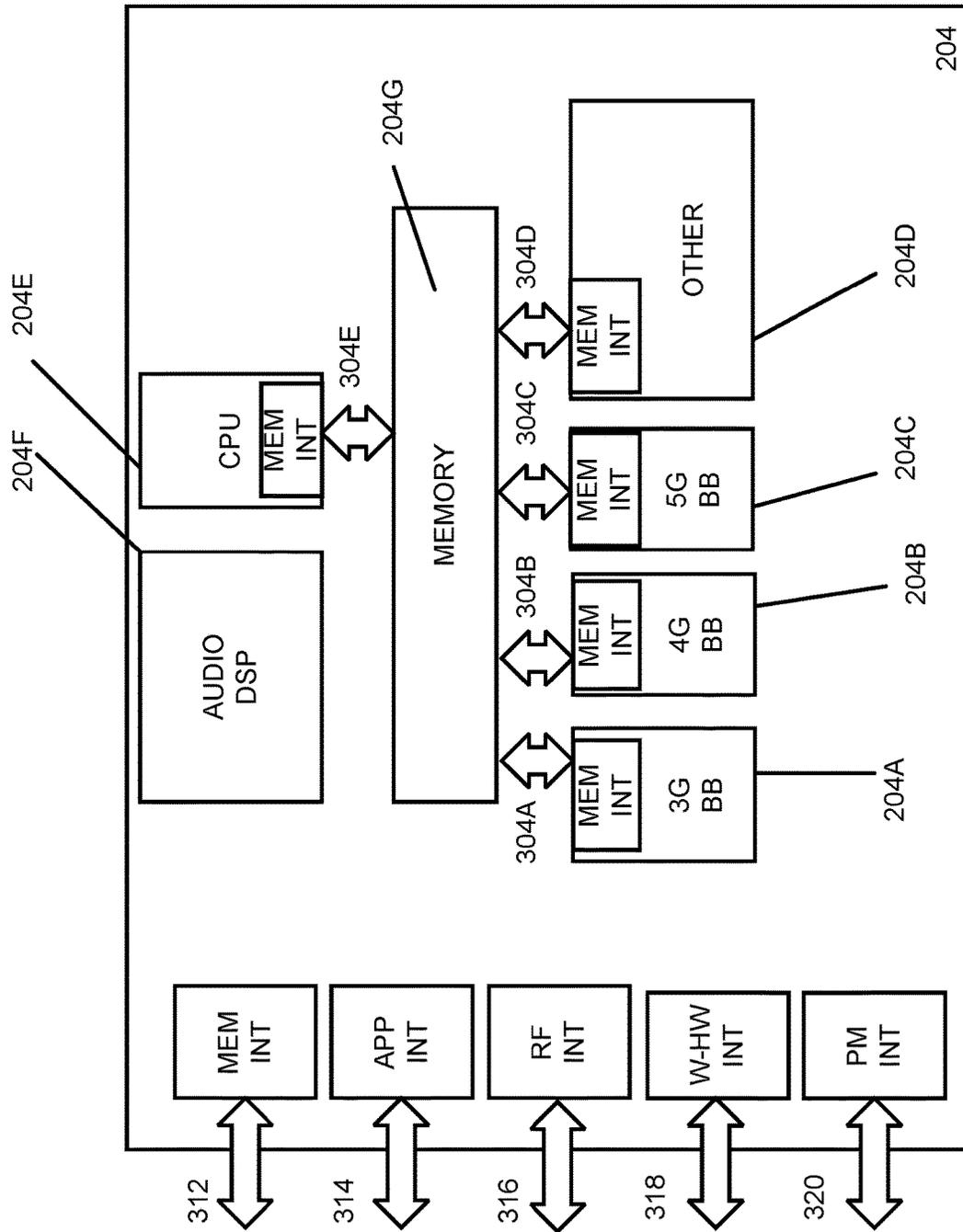


FIG. 3

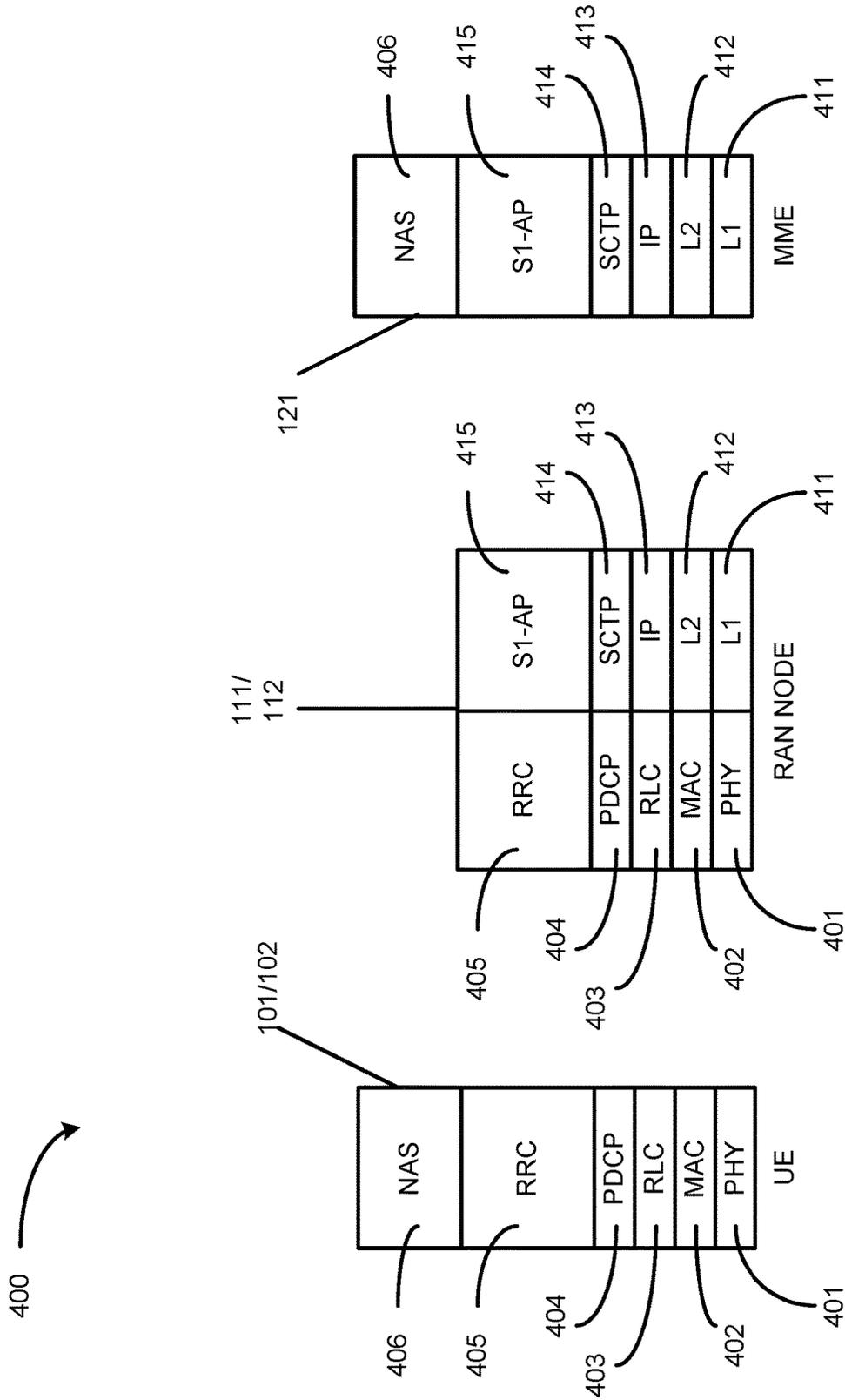


FIG. 4

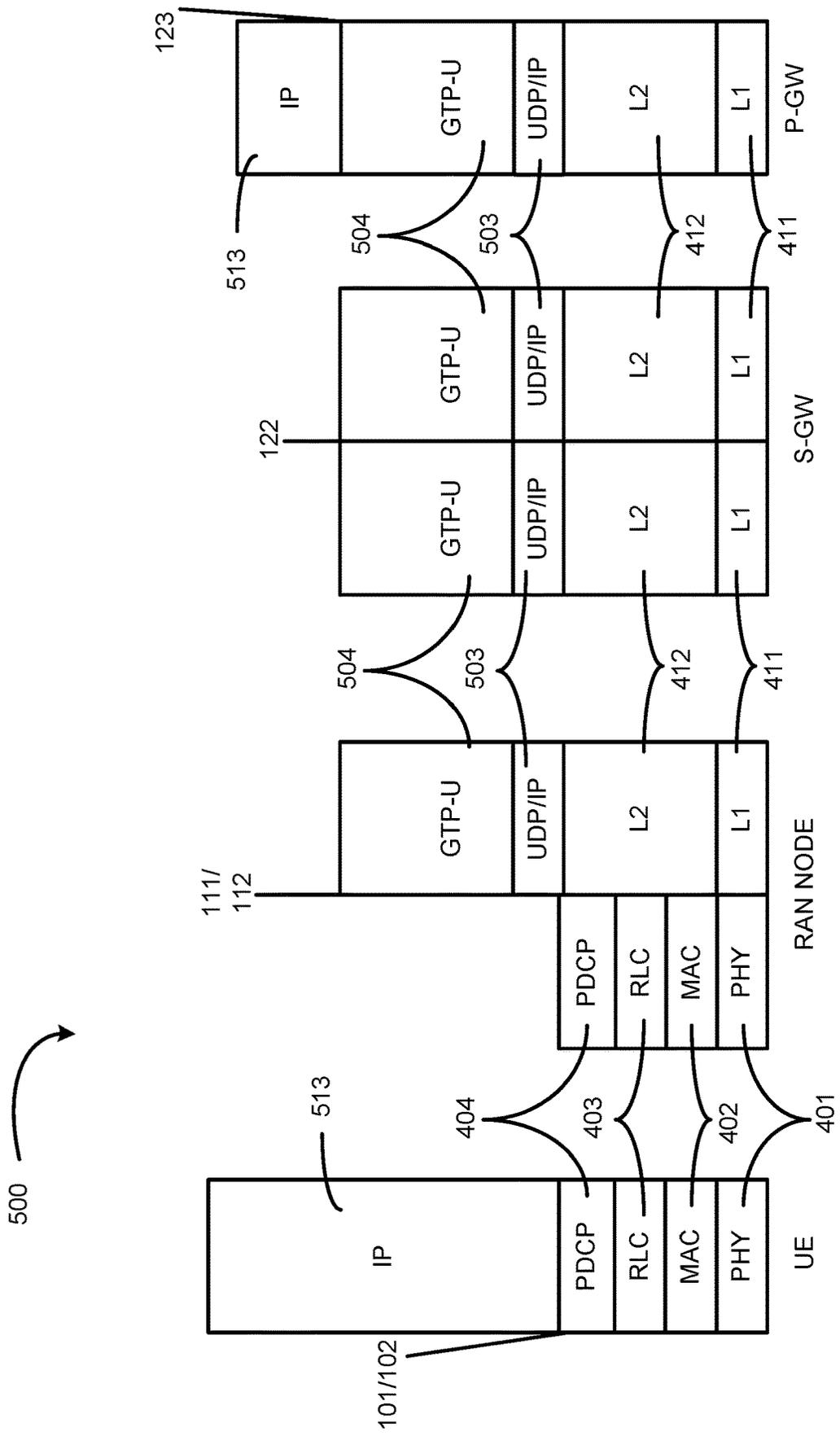
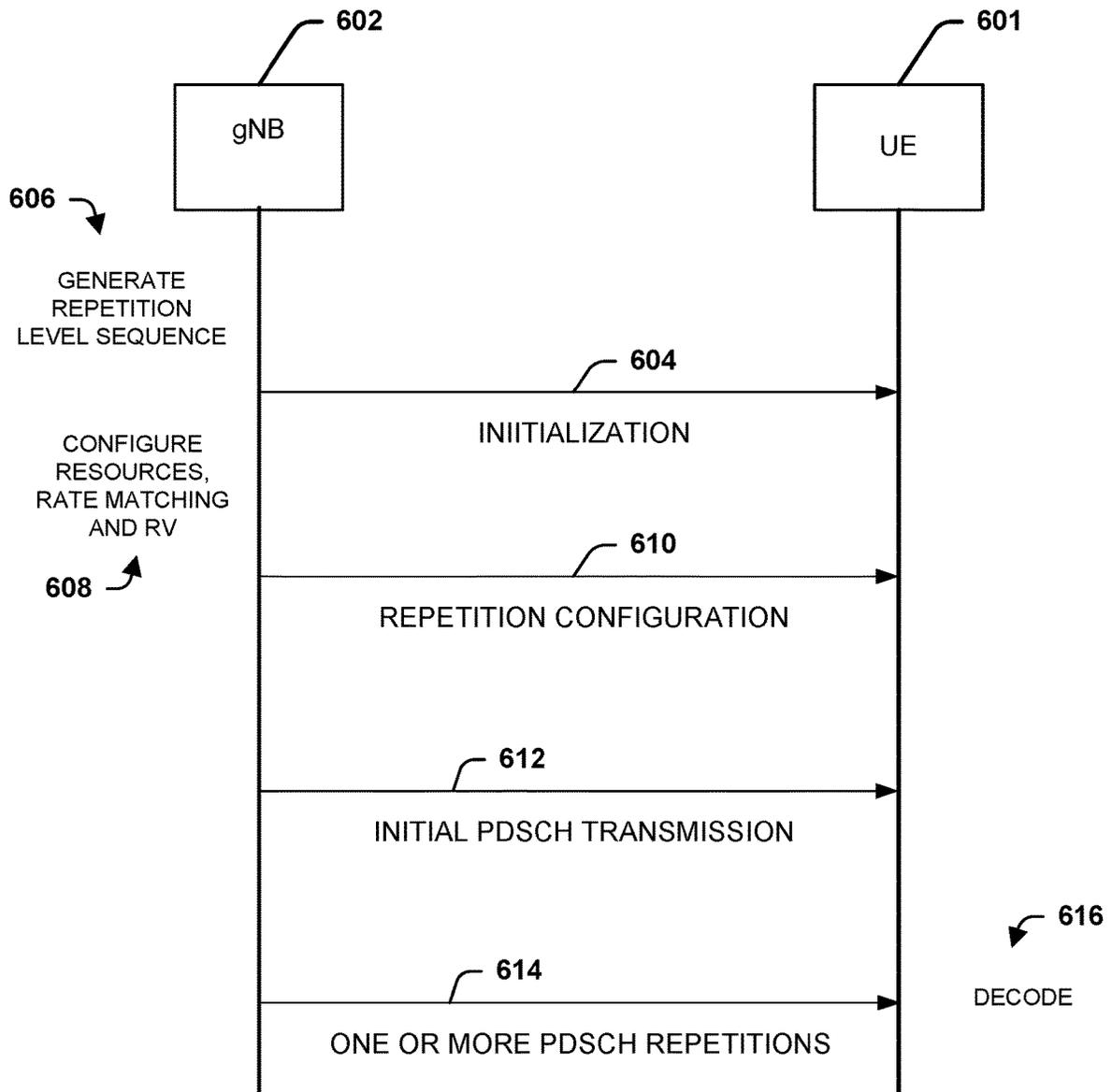


FIG. 5



600 ↗

FIG. 6

DCI bit field	Sub-frame	Slot or sub-slot
00	1 (no repetition)	1 (no repetition)
01	2	2
10	4	3
11	8	6

700 

DCI Fields for repetitions

FIG. 7

- RV0 => starting index 0 in the RV cycling sequence
- RV1 => starting index 3 in the RV cycling sequence
- RV2 => starting index 1 in the RV cycling sequence
- RV3 => starting index 2 in the RV cycling sequence

900 

RV Cycling

FIG. 9

Mode #	Initial transmission (legacy behavior)	Repetition
1	UE rate-matches only around the sDCI scheduling the sPDSCH (if transmitted in the sPDCCH RB-set), otherwise no rate-matching is performed for the RB set	Option 1: UE follows the same rate-matching mode as associated with the initial transmission Option 2: UE does not perform rate-matching for the RB set
2	UE rate-matches around the whole sPDCCH RB set	UE rate-matches around the whole sPDCCH RB set
3	UE rate-matches around the whole sPDCCH RB set if sDCI scheduling the sPDSCH is found in the RB-set, otherwise no rate-matching is performed for the RB set	Option 1: UE follows the same rate-matching mode as associated with the initial transmission Option 2: UE does not perform rate-matching for the RB set
4	UE rate-matches around the whole sPDCCH RB set if sDCI scheduling the sPDSCH is not found in the RB-set, otherwise UE rate-matches only around the sDCI scheduling the sPDSCH (if transmitted in the sPDCCH RB-set)	UE rate-matches around the whole sPDCCH RB set

800 

FIG. 8

SYSTEMS AND METHODS FOR PHYSICAL CHANNEL REPETITION FOR LOW LATENCY COMMUNICATION

REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/670,642, filed May 11, 2018, the contents of which are herein incorporated by reference in their entirety.

FIELD

Various embodiments generally relate to the field of wireless communications.

BACKGROUND

Wireless or mobile communication involves wireless communication between two or more devices. The communication requires resources to transmit data from one device to another and/or to receive data at one device from another.

Some important aspects of communication include latency and reliability. This latency involves a delay in sending communications. Various applications using communication can depend on low latency based communications.

What is needed are techniques to mitigate and/or reduce latency and enhance reliability for wireless communication systems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a block diagram of an example wireless communications network environment for a network device (e.g., a UE, gNB or an eNB) according to various aspects or embodiments.

FIG. 2 illustrates another block diagram of an example of wireless communications network environment for a network device (e.g., a UE, gNB or an eNB) according to various aspects or embodiments.

FIG. 3 another block diagram of an example of wireless communications network environment for network device (e.g., a UE, gNB or an eNB) with various interfaces according to various aspects or embodiments.

FIG. 4 is an illustration of a control plane protocol stack in accordance with some embodiments.

FIG. 5 is an illustration of a user plane protocol stack in accordance with some embodiments.

FIG. 6 is a diagram illustrating an architecture of a system that facilitates wireless communication by providing physical channel repetition in accordance with one or more embodiments.

FIG. 7 is a table illustrating an example mapping of DCI fields for repetitions in accordance with one or more embodiments.

FIG. 8 is a table illustrating potential UE behavior for repetitions configured with a resource sharing mode in accordance with one or more embodiments

FIG. 9 illustrates examples of an RV fields or values for scheduling transmissions in accordance with one or more embodiments.

DETAILED DESCRIPTION

The present disclosure will now be described with reference to the attached drawing figures, wherein like reference

numerals are used to refer to like elements throughout, and wherein the illustrated structures and devices are not necessarily drawn to scale. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail. Embodiments herein may be related to RAN1, RAN2, 5G and the like.

As utilized herein, terms “component,” “system,” “interface,” and the like are intended to refer to a computer-related entity, hardware, software (e.g., in execution), and/or firmware. For example, a component can be a processor, a process running on a processor, a controller, an object, an executable, a program, a storage device, and/or a computer with a processing device. By way of illustration, an application running on a server and the server can also be a component. One or more components can reside within a process, and a component can be localized on one computer and/or distributed between two or more computers. A set of elements or a set of other components can be described herein, in which the term “set” can be interpreted as “one or more.”

Further, these components can execute from various computer readable storage media having various data structures stored thereon such as with a module, for example. The components can communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network, such as, the Internet, a local area network, a wide area network, or similar network with other systems via the signal).

As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, in which the electric or electronic circuitry can be operated by a software application or a firmware application executed by one or more processors. The one or more processors can be internal or external to the apparatus and can execute at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts; the electronic components can include one or more processors therein to execute software and/or firmware that confer(s), at least in part, the functionality of the electronic components.

Use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise

or clear from context to be directed to a singular form. Furthermore, to the extent that the terms “including”, “includes”, “having”, “has”, “with”, or variants thereof are used in either the detailed description and the claims, such terms are intended to be inclusive in a manner similar to the term “comprising”.

Mobile communication has evolved from early voice systems to highly sophisticated integrated communication systems or platforms. Next generation wireless/mobile communication systems, such as 5G and new radio (NR) are expected to be a unified network/system that targets to meet different and even conflicting performance dimensions and services. Such diverse multi-dimensional requirements are driven by different services and applications. Generally, NR will evolve based on 3GPP LTE-Advanced with additional potential new radio access. Further, NR is expected to evolve with additional potential new radio access technologies (RATs) to enrich mobile communication with improved, simple and seamless wireless connectivity solutions. NR can enable mobile communication that provides fast and rich contents and services.

It is appreciated that physical downlink channel repetitions can be used to enable ultra-reliable low latency communication (URLLC) for LTE in Rel.15. The physical downlink channels include physical downlink shared channels (PDSCH).

The PDSCH repetitions are the number of times the channel is repeated. By repeating the transmission, the channel is more likely to be received by the receiver. Additionally, retransmissions via HARQ and the like can be mitigated.

The PDSCH repetitions can be configured for short transmission time interval (TTI) and regular TTI operation to comply with URLLC requirements and the like. The PDSCH repetitions also provide lower spectrum efficiency for transmissions without changes to a modulation and coding scheme (MCS) table.

One or more embodiments are disclosed that facilitate communications by providing dynamical physical channel repetitions. The embodiments include using downlink control information (DCI) and the like to convey repetition information/configuration to a user equipment (UE) device. The embodiments also include rate-matching behavior and resource sharing modes for initial transmission and repetitions or retransmissions. The embodiments also include using different redundancy versions (RV) for repetitions or retransmissions and supporting RV cycling across physical channel repetitions (e.g., PDSCH repetitions). The embodiments also include a DCI design or configuration to support physical channel repetitions.

FIG. 1 illustrates an architecture of a system **100** of a network in accordance with some embodiments. The system **100** is shown to include a user equipment (UE) **101** and a UE **102**. The UEs **101** and **102** are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but can also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface.

In some embodiments, any of the UEs **101** and **102** can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public

land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data can be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which can include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs can execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

The UEs **101** and **102** can be configured to connect, e.g., communicatively couple, with a radio access network (RAN) **110**—the RAN **110** can be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs **101** and **102** utilize connections **103** and **104**, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections **103** and **104** are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

In this embodiment, the UEs **101** and **102** can further directly exchange communication data via a ProSe interface **105**. The ProSe interface **105** can alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

The UE **102** is shown to be configured to access an access point (AP) **106** via connection **107**. The connection **107** can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP **106** would comprise a wireless fidelity (WiFi®) router. In this example, the AP **106** is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

The RAN **110** can include one or more access nodes that enable the connections **103** and **104**. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). A network device as referred to herein can include any one of these APs, ANs, UEs or any other network component. The RAN **110** can include one or more RAN nodes for providing macrocells, e.g., macro RAN node **111**, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node **112**.

Any of the RAN nodes **111** and **112** can terminate the air interface protocol and can be the first point of contact for the UEs **101** and **102**. In some embodiments, any of the RAN nodes **111** and **112** can fulfill various logical functions for the RAN **110** including, but not limited to, radio network controller (RNC) functions such as radio bearer manage-

ment, uplink (UL) and downlink (DL) dynamic radio resource management and data packet scheduling, and mobility management.

In accordance with some embodiments, the UEs **101** and **102** can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes **111** and **112** over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes **111** and **112** to the UEs **101** and **102**, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this can represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

The physical downlink shared channel (PDSCH) can carry user data and higher-layer signaling to the UEs **101** and **102**. The physical downlink control channel (PDCCH) can carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It is appreciated that an MTC physical downlink control channel (MPDCCH) and/or an enhanced physical downlink control channel (EPDCCH) can be used in place of the PDCCH. It can also inform the UEs **101** and **102** about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE **102** within a cell) can be performed at any of the RAN nodes **111** and **112** based on channel quality information fed back from any of the UEs **101** and **102**. The downlink resource assignment information can be sent on the PDCCH used for (e.g., assigned to) each of the UEs **101** and **102**.

The PDCCH can use control channel elements (CCEs) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols can first be organized into quadruplets, which can then be permuted using a sub-block interleaver for rate matching. Each PDCCH can be transmitted using one or more of these CCEs, where each CCE can correspond to nine sets of four physical resource elements known as resource element groups (REGs). Four Quadrature Phase Shift Keying (QPSK) symbols can be mapped to each REG. The PDCCH

can be transmitted using one or more CCEs, depending on the size of the downlink control information (DCI) and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, $L=1, 2, 4, \text{ or } 8$).

Some embodiments can use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments can utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH can be transmitted using one or more enhanced control channel elements (ECCEs). Similar to above, each ECCE can correspond to nine sets of four physical resource elements known as an enhanced resource element groups (EREGs). An ECCE can have other numbers of EREGs in some situations.

The RAN **110** is shown to be communicatively coupled to a core network (CN) **120**—via an S1 interface **113**. In embodiments, the CN **120** can be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment the S1 interface **113** is split into two parts: the S1-U interface **114**, which carries traffic data between the RAN nodes **111** and **112** and the serving gateway (S-GW) **122**, and the S1-mobility management entity (MME) interface **115**, which is a signaling interface between the RAN nodes **111** and **112** and MMEs **121**.

In this embodiment, the CN **120** comprises the MMEs **121**, the S-GW **122**, the Packet Data Network (PDN) Gateway (P-GW) **123**, and a home subscriber server (HSS) **124**. The MMEs **121** can be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs **121** can manage mobility aspects in access such as gateway selection and tracking area list management. The HSS **124** can comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN **120** can comprise one or several HSSs **124**, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS **124** can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

The S-GW **122** can terminate the S1 interface **113** towards the RAN **110**, and routes data packets between the RAN **110** and the CN **120**. In addition, the S-GW **122** can be a local mobility anchor point for inter-RAN node handovers and also can provide an anchor for inter-3GPP mobility. Other responsibilities can include lawful intercept, charging, and some policy enforcement.

The P-GW **123** can terminate an SGi interface toward a PDN. The P-GW **123** can route data packets between the CN network **120** and external networks such as a network including the application server **130** (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface **125**. Generally, the application server **130** can be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW **123** is shown to be communicatively coupled to an application server **130** via an IP communications interface **125**. The application server **130** can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group

communication sessions, social networking services, etc.) for the UEs **101** and **102** via the CN **120**.

The P-GW **123** can further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) **126** is the policy and charging control element of the CN **120**. In a non-roaming scenario, there can be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there can be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF **126** can be communicatively coupled to the application server **130** via the P-GW **123**. The application server **130** can signal the PCRF **126** to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF **126** can provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server **130**.

In one or more embodiments, IMS services can be identified more accurately in a paging indication, which can enable the UEs **101**, **102** to differentiate between PS paging and IMS service related paging. As a result, the UEs **101**, **102** can apply preferential prioritization for IMS services as desired based on any number of requests by any application, background searching (e.g., PLMN searching or the like), process, or communication. In particular, the UEs **101**, **102** can differentiate the PS domain paging to more distinguishable categories, so that IMS services can be identified clearly in the UEs **101**, **102** in comparison to PS services. In addition to a domain indicator (e.g., PS or CS), a network (e.g., CN **120**, RAN **110**, AP **106**, or combination thereof as an eNB or the other network device) can provide further, more specific information with the TS 36.331-Paging message, such as a "paging cause" parameter. The UE can use this information to decide whether to respond to the paging, possibly interrupting some other procedure like an ongoing PLMN search.

In one example, when UEs **101**, **102** can be registered to a visited PLMN (VPLMN) and performing PLMN search (i.e., background scan for a home PLMN (HPLMN) or a higher priority PLMN), or when a registered UE is performing a manual PLMN search, the PLMN search can be interrupted in order to move to a connected mode and respond to a paging operation as part of a MT procedure/operation. Frequently, this paging could be for PS data (non-IMS data), where, for example, an application server **130** in the NW wants to push to the UE **101** or **102** for one of the many different applications running in/on the UE **101** or **102**, for example. Even though the PS data could be delay tolerant and less important, in legacy networks the paging is often not able to be ignored completely, as critical services like an IMS call can be the reason for the PS paging. The multiple interruptions of the PLMN search caused by the paging can result in an unpredictable delay of the PLMN search or in the worst case even in a failure of the procedure, resulting in a loss of efficiency in network communication operations. A delay in moving to or handover to a preferred PLMN (via manual PLMN search or HPLMN search) in a roaming condition can incur more roaming charges on a user as well.

FIG. 2 illustrates example components of a network device **200** in accordance with some embodiments. In some

embodiments, the device **200** can include application circuitry **202**, baseband circuitry **204**, Radio Frequency (RF) circuitry **206**, front-end module (FEM) circuitry **208**, one or more antennas **210**, and power management circuitry (PMC) **212** coupled together at least as shown. The components of the illustrated device **200** can be included in a UE **101**, **102** or a RAN node **111**, **112**, AP, AN, eNB or other network component. In some embodiments, the device **200** can include less elements (e.g., a RAN node cannot utilize application circuitry **202**, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the network device **200** can include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below can be included in more than one device (e.g., said circuitries can be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

The application circuitry **202** can include one or more application processors. For example, the application circuitry **202** can include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) can include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors can be coupled with or can include memory/storage and can be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device **200**. In some embodiments, processors of application circuitry **202** can process IP data packets received from an EPC.

The baseband circuitry **204** can include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry **204** can include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry **206** and to generate baseband signals for a transmit signal path of the RF circuitry **206**. Baseband processing circuitry **204** can interface with the application circuitry **202** for generation and processing of the baseband signals and for controlling operations of the RF circuitry **206**. For example, in some embodiments, the baseband circuitry **204** can include a third generation (3G) baseband processor **204A**, a fourth generation (4G) baseband processor **204B**, a fifth generation (5G) baseband processor **204C**, or other baseband processor(s) **204D** for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry **204** (e.g., one or more of baseband processors **204A-D**) can handle various radio control functions that enable communication with one or more radio networks via the RF circuitry **206**. In other embodiments, some or all of the functionality of baseband processors **204A-D** can be included in modules stored in the memory **204G** and executed via a Central Processing Unit (CPU) **204E**. The radio control functions can include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry **204** can include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry **204** can include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not

limited to these examples and can include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry **204** can include one or more audio digital signal processor(s) (DSP) **204F**. The audio DSP(s) **204F** can include elements for compression/decompression and echo cancellation and can include other suitable processing elements in other embodiments. Components of the baseband circuitry can be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry **204** and the application circuitry **202** can be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry **204** can provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry **204** can support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry **204** is configured to support radio communications of more than one wireless protocol can be referred to as multi-mode baseband circuitry.

RF circuitry **206** can enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry **206** can include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry **206** can include a receive signal path which can include circuitry to down-convert RF signals received from the FEM circuitry **208** and provide baseband signals to the baseband circuitry **204**. RF circuitry **206** can also include a transmit signal path which can include circuitry to up-convert baseband signals provided by the baseband circuitry **204** and provide RF output signals to the FEM circuitry **208** for transmission.

In some embodiments, the receive signal path of the RF circuitry **206** can include mixer circuitry **206a**, amplifier circuitry **206b** and filter circuitry **206c**. In some embodiments, the transmit signal path of the RF circuitry **206** can include filter circuitry **206c** and mixer circuitry **206a**. RF circuitry **206** can also include synthesizer circuitry **206d** for synthesizing a frequency for use by the mixer circuitry **206a** of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry **206a** of the receive signal path can be configured to down-convert RF signals received from the FEM circuitry **208** based on the synthesized frequency provided by synthesizer circuitry **206d**. The amplifier circuitry **206b** can be configured to amplify the down-converted signals and the filter circuitry **206c** can be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals can be provided to the baseband circuitry **204** for further processing. In some embodiments, the output baseband signals can be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry **206a** of the receive signal path can comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry **206a** of the transmit signal path can be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry **206d** to generate RF output signals for the FEM circuitry **208**. The baseband

signals can be provided by the baseband circuitry **204** and can be filtered by filter circuitry **206c**.

In some embodiments, the mixer circuitry **206a** of the receive signal path and the mixer circuitry **206a** of the transmit signal path can include two or more mixers and can be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry **206a** of the receive signal path and the mixer circuitry **206a** of the transmit signal path can include two or more mixers and can be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry **206a** of the receive signal path and the mixer circuitry **206a** can be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry **206a** of the receive signal path and the mixer circuitry **206a** of the transmit signal path can be configured for super-heterodyne operation.

In some embodiments, the output baseband signals and the input baseband signals can be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals can be digital baseband signals. In these alternate embodiments, the RF circuitry **206** can include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry **204** can include a digital baseband interface to communicate with the RF circuitry **206**.

In some dual-mode embodiments, a separate radio IC circuitry can be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

In some embodiments, the synthesizer circuitry **206d** can be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers can be suitable. For example, synthesizer circuitry **206d** can be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry **206d** can be configured to synthesize an output frequency for use by the mixer circuitry **206a** of the RF circuitry **206** based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry **206d** can be a fractional N/N+1 synthesizer.

In some embodiments, frequency input can be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input can be provided by either the baseband circuitry **204** or the applications processor **202** depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) can be determined from a look-up table based on a channel indicated by the applications processor **202**.

Synthesizer circuitry **206d** of the RF circuitry **206** can include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider can be a dual modulus divider (DMD) and the phase accumulator can be a digital phase accumulator (DPA). In some embodiments, the DMD can be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL can include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements can be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements

in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

In some embodiments, synthesizer circuitry **206d** can be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency can be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency can be a LO frequency (f_{LO}). In some embodiments, the RF circuitry **206** can include an IQ/polar converter.

FEM circuitry **208** can include a receive signal path which can include circuitry configured to operate on RF signals received from one or more antennas **210**, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry **206** for further processing. FEM circuitry **208** can also include a transmit signal path which can include circuitry configured to amplify signals for transmission provided by the RF circuitry **206** for transmission by one or more of the one or more antennas **210**. In various embodiments, the amplification through the transmit or receive signal paths can be done solely in the RF circuitry **206**, solely in the FEM **208**, or in both the RF circuitry **206** and the FEM **208**.

In some embodiments, the FEM circuitry **208** can include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry can include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry can include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry **206**). The transmit signal path of the FEM circuitry **208** can include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry **206**), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas **210**).

In some embodiments, the PMC **212** can manage power provided to the baseband circuitry **204**. In particular, the PMC **212** can control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC **212** can often be included when the device **200** is capable of being powered by a battery, for example, when the device is included in a UE. The PMC **212** can increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

While FIG. 2 shows the PMC **212** coupled only with the baseband circuitry **204**. However, in other embodiments, the PMC **212** can be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry **202**, RF circuitry **206**, or FEM **208**.

In some embodiments, the PMC **212** can control, or otherwise be part of, various power saving mechanisms of the device **200**. For example, if the device **200** is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it can enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device **200** can power down for brief intervals of time and thus save power.

If there is no data traffic activity for an extended period of time, then the device **200** can transition off to an RRC Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, han-

dover, etc. The device **200** goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device **200** does not receive data in this state, in order to receive data, it transitions back to RRC_Connected state.

An additional power saving mode can allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device can be unreachable to the network and can power down completely. Any data sent during this time can incur a large delay with the delay presumed to be acceptable.

Processors of the application circuitry **202** and processors of the baseband circuitry **204** can be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry **204**, alone or in combination, can be used to execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry **202** can utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 can comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 can comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 can comprise a physical (PHY) layer of a UE/RAN node. Each of these layers can be implemented to operate one or more processes or network operations of embodiments/aspects herein.

In addition, the memory **204G** can comprise one or more machine-readable medium/media including instructions that, when performed by a machine or component herein cause the machine to perform acts of the method or of an apparatus or system for concurrent communication using multiple communication technologies according to embodiments and examples described herein. It is to be understood that aspects described herein can be implemented by hardware, software, firmware, or any combination thereof. When implemented in software, functions can be stored on or transmitted over as one or more instructions or code on a computer-readable medium (e.g., the memory described herein or other storage device). Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media or a computer readable storage device can be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or other tangible and/or non-transitory medium, that can be used to carry or store desired information or executable instructions. Also, any connection can also be termed a computer-readable medium. For example, if software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium.

In general, there is a move to provide network services for the packet domain. The earlier network services like UMTS or 3G and predecessors (2G) configured a CS domain and a packet domain providing different services, especially CS

services in the CS domain as well as voice services were considered to have a higher priority because consumers demanded an immediate response. Based on the domain that the paging was received, the device **200** could assign certain priority for the incoming transaction. Now with LTE/5G most services are moving to the packet domain. Currently, the UE (e.g., **101**, **102**, or device **200**) can get paging for a packet service without knowing any further information about the paging of the MT procedure, such as whether someone is calling on a line, a VoIP call, or just some packet utilized from Facebook, other application service, or other similar MT service. As such, a greater opportunity exists for further delays without the possibility for the UE to discriminate between the different application packets that could initiate a paging and also give a different priority to it based on one or more user preferences. This can be important for the UE because the UE might be doing other tasks more vital for resource allocation.

In one example, a UE (e.g., **101**, **102**, or device **200**) could be performing a background search for other PLMNs. This is a task the UE device **200** could do in regular intervals if it is not connected on its own home PLMN or a higher priority PLMN, but roaming somewhere else. A higher priority could be a home PLMN or some other PLMNs according to a list provided by the provider or subscriber (e.g., HSS **124**). Consequently, if a paging operation arrives as an MT service and an interruption results, such that a start and begin operation are executed, a sufficient frequency of these interruptions could cause the UE to never complete a background search in a reasonable way. This is one way where it would be advantageous for the UE or network device to know that the interruption is only a packet service, with no need to react to it immediately, versus an incoming voice call that takes preference immediately and the background scan should be postponed.

Additionally, the device **200** can be configured to connect or include multiple subscriber identity/identification module (SIM) cards/components, referred to as dual SIM or multi SIM devices. The device **200** can operate with a single transmit and receive component that can coordinate between the different identities from which the SIM components are operating. As such, an incoming voice call should be responded to as fast as possible, while only an incoming packet for an application could be relatively ignored in order to utilize resources for the other identity (e.g., the voice call or SIM component) that is more important or has a higher priority from a priority list/data set/or set of user device preferences, for example. This same scenario can also be utilized for other operations or incoming data, such as with a PLMN background search such as a manual PLMN search, which can last for a long period of time since, especially with a large number of different bands from 2G, etc. With an ever increasing number of bands being utilized in wireless communications, if paging interruptions come in between the operations already running without distinguishing between the various packet and real critical services such as voice, the network devices can interpret this manual PLMN search to serve and ensure against a drop or loss of any increment voice call, with more frequent interruptions in particular.

As stated above, even though in most of these cases the PS data is delay tolerant and less important, in legacy networks the paging cannot be ignored completely, as critical services like an IMS call can be the reason for the PS paging. The multiple interruptions of a PLMN search caused by the paging can result in an unpredictable delay of the PLMN search or in the worst case even in a failure of the

procedure. Additionally, a delay in moving to preferred PLMN (via manual PLMN search or HPLMN search) in roaming condition can incur more roaming charges on user. Similarly, in multi-SIM scenario when UE is listening to paging channel of two networks simultaneously and has priority for voice service, a MT IMS voice call can be interpreted as "data" call as indicated in MT paging message and can be preceded by MT Circuit Switched (CS) paging of an other network or MO CS call initiated by user at same time. As such, embodiments/aspects herein can increase the call drop risk significantly for the SIM using IMS voice service.

In embodiments, 3GPP NW can provide further granular information about the kind of service the network is paging for. For example, the Paging cause parameter could indicate one of the following values/classes/categories: 1) IMS voice/video service; 2) IMS SMS service; 3) IMS other services (not voice/video/SMS-related); 4) any IMS service; 5) Other PS service (not IMS-related). In particular, a network device (e.g., an eNB or access point) could only be discriminating between IMS and non-IMS services could use 4) and 5), whereas a network that is able to discriminate between different types of IMS services (like voice/video call, SMS, messaging, etc.) could use 3) instead of 4) to explicitly indicate to the UE that the paging is for an IMS service different from voice/video and SMS. By obtaining this information UE may decide to suspend PLMN search only for critical services like incoming voice/video services.

In other aspects, dependent on the service category (e.g., values or classes 1-5 above), the UE **101**, **102**, or device **200** can memorize that there was a paging to which it did not respond, and access the network later, when the PLMN search has been completed and the UE decides to stay on the current PLMN. For example, if the reason for the paging was a mobile terminating IMS SMS, the MME can then inform the HSS (e.g., **124**) that the UE is reachable again, and the HSS **124** can initiate a signaling procedure which will result in a delivery of the SMS to the UE once resources are more available or less urgent for another operation/application/or category, for example. To this purpose the UE **101**, **102**, or **200** could initiate a periodic tau area update (TAU) procedure if the service category in the Paging message indicated "IMS SMS service", for example.

FIG. 3 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry **204** of FIG. 2 can comprise processors **204A-204E** and a memory **204G** utilized by said processors. Each of the processors **204A-204E** can include a memory interface, **304A-304E**, respectively, to send/receive data to/from the memory **204G**.

The baseband circuitry **204** can further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface **312** (e.g., an interface to send/receive data to/from memory external to the baseband circuitry **204**), an application circuitry interface **314** (e.g., an interface to send/receive data to/from the application circuitry **202** of FIG. 2), an RF circuitry interface **316** (e.g., an interface to send/receive data to/from RF circuitry **206** of FIG. 2), a wireless hardware connectivity interface **318** (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface **320** (e.g., an interface to send/receive power or control signals to/from the PMC **212**).

FIG. 4 is an illustration of a control plane protocol stack in accordance with some embodiments. In this embodiment,

a control plane **400** is shown as a communications protocol stack between the UE **101** (or alternatively, the UE **102**), the RAN node **111** (or alternatively, the RAN node **112**), and the MME **121**.

The PHY layer **401** may transmit or receive information used by the MAC layer **402** over one or more air interfaces. The PHY layer **401** may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC layer **405**. The PHY layer **401** may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and Multiple Input Multiple Output (MIMO) antenna processing.

The MAC layer **402** may perform mapping between logical channels and transport channels, multiplexing of MAC service data units (SDUs) from one or more logical channels onto transport blocks (TB) to be delivered to PHY via transport channels, de-multiplexing MAC SDUs to one or more logical channels from transport blocks (TB) delivered from the PHY via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), and logical channel prioritization.

The RLC layer **403** may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC layer **403** may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC layer **403** may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

The PDCP layer **404** may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

The main services and functions of the RRC layer **405** may include broadcast of system information (e.g., included in Master Information Blocks (MIBs) or System Information Blocks (SIBs) related to the non-access stratum (NAS)), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting. Said MIBs and SIBs may comprise

one or more information elements (IEs), which may each comprise individual data fields or data structures.

The UE **101** and the RAN node **111** may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange control plane data via a protocol stack comprising the PHY layer **401**, the MAC layer **402**, the RLC layer **403**, the PDCP layer **404**, and the RRC layer **405**.

The non-access stratum (NAS) protocols **406** form the highest stratum of the control plane between the UE **101** and the MME **121**. The NAS protocols **406** support the mobility of the UE **101** and the session management procedures to establish and maintain IP connectivity between the UE **101** and the P-GW **123**.

The S1 Application Protocol (S1-AP) layer **415** may support the functions of the S1 interface and comprise Elementary Procedures (EPs). An EP is a unit of interaction between the RAN node **111** and the CN **120**. The S1-AP layer services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

The Stream Control Transmission Protocol (SCTP) layer (alternatively referred to as the SCTP/IP layer) **414** may ensure reliable delivery of signaling messages between the RAN node **111** and the MME **121** based, in part, on the IP protocol, supported by the IP layer **413**. The L2 layer **412** and the L1 layer **411** may refer to communication links (e.g., wired or wireless) used by the RAN node and the MME to exchange information.

The RAN node **111** and the MME **121** may utilize an S1-MME interface to exchange control plane data via a protocol stack comprising the L1 layer **411**, the L2 layer **412**, the IP layer **413**, the SCTP layer **414**, and the S1-AP layer **415**.

FIG. 5 is an illustration of a user plane protocol stack in accordance with some embodiments. In this embodiment, a user plane **500** is shown as a communications protocol stack between the UE **101** (or alternatively, the UE **102**), the RAN node **111** (or alternatively, the RAN node **112**), the S-GW **122**, and the P-GW **123**. The user plane **500** may utilize at least some of the same protocol layers as the control plane **400**. For example, the UE **101** and the RAN node **111** may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange user plane data via a protocol stack comprising the PHY layer **401**, the MAC layer **402**, the RLC layer **403**, the PDCP layer **404**.

The General Packet Radio Service (GPRS) Tunneling Protocol for the user plane (GTP-U) layer **504** may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP and IP security (UDP/IP) layer **503** may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node **111** and the S-GW **122** may utilize an S1-U interface to exchange user plane data via a protocol stack comprising the L1 layer **411**, the L2 layer **412**, the UDP/IP layer **503**, and the GTP-U layer **504**. The S-GW **122** and the P-GW **123** may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising the L1 layer **411**, the L2 layer **412**, the UDP/IP layer **503**, and the GTP-U layer **504**. As discussed above with respect to FIG. 4, NAS protocols support the mobility

of the UE **101** and the session management procedures to establish and maintain IP connectivity between the UE **101** and the P-GW **123**.

FIG. 6 is a diagram illustrating an architecture of a system **600** that facilitates wireless communication by providing physical channel repetition in accordance with one or more embodiments. The system or apparatus **600** can be utilized with the above embodiments and variations thereof, including the system **100** described above. The system **600** is provided as an example and it is appreciated that suitable variations are contemplated.

The system **600** facilitates and provides dynamic indication of physical channel repetitions and UE device performance. The physical channels include physical downlink shared channels (PDSCH), sPDSCH and the like. The dynamic indication is provided for varied situations including, but not limited to regular duration transmission time intervals (TTIs) and short duration TTIs.

A physical downlink control channel (PDCCH) and PDSCH having a short TTI are respectively termed the sPDCCH and sPDSCH. For ease of explanation, a PDSCH or PDCCH can be described, however it is appreciated that sPDSCH and sPDCCH can also be utilized.

The system **600** includes a network device **601** and a node **602**. The device **601** is shown as a UE device and the node **602** is shown as gNB for illustrative purposes. It is appreciated that the UE device **601** can be other network devices, such as APs, ANs and the like. It is also appreciated that the gNB **602** can be other nodes or access nodes (ANs), such as a base station (BS), eNB, gNB, RAN nodes, UE and the like. Other network or network devices can be present and interact with the device **601** and/or the node **602**. Operation of the device **601** and/or the node **602** can be performed by circuitry, such as the baseband circuitry **204**, described above.

Generally, downlink (DL) transmissions occur from the gNB **602** to the UE **601** whereas uplink (UL) transmissions occur from the UE **601** to the gNB **602**. The downlink transmissions typically utilize a DL control channel and a DL data channel. The uplink transmissions typically utilize an UL control channel and a UL data channel. The various channels can be different in terms of direction, link to another gNB, eNB and the like.

The UE **601** is typically one of a set or group of UE devices assigned to or associated with a cell of the gNB **602**. The UE **601** can be configured with a secondary cell group (SCG) and/or a master cell group (MCG). Within a cell group, there can be a primary cell, secondary cell, serving cell and the like that belong with the group. The UE **601** can be associated or configured with one or more cell within the cell group.

The gNB **602** is configured to initialize communication with the UE **601** at **604**.

The gNB **602** is also configured to generate repetition configuration for physical downlink shared channel(s) (PDSCH) or sPDSCH. The repetition configuration can include generation of a repetition level sequence **606** and resource (resource blocks (RBs)), rate matching and redundancy versions (RVs) PDSCH repetitions.

The gNB **602** is configured to provide the repetition configuration to the UE **601** at **610**. The configuration includes a number of physical downlink shared channel (PDSCH) repetitions for downlink transmissions.

The gNB **602** is configured to generate an initial PDSCH transmission at **612**. The initial PDSCH transmission is performed using initial RBs and initial rate matching for the PDSCH transmission.

The gNB **602** is configured to generate one or more PDSCH repetitions at **614**. The one or more repetitions are in accordance with the repetition configuration provided at **610**. The configuration can include repetition RBs, repetition rate matching and the like.

The UE **601** is configured to decode the one or more PDSCH repetitions using the repetition configuration at **616**.

In one example, the gNB **602** can be configured to generate a physical downlink control channel (PDCCH) that includes the repetition configuration, including the number of repetitions. This number of repetitions indicates the number of repeating PDSCH transmissions associated with the PDCCH. It is appreciated that the PDCCH may or may not be transmitted with a PDSCH repetition. The PDSCH transmissions can be soft combined after a PDCCH is successfully received by the UE **601**.

The number of transmissions, k , is the number of PDSCH transmissions associated with the PDCCH starting with the current TTI.

The UE **601** is configured to support repetition based PDSCH reception.

The UE **601** can discard any/a PDSCH assignment for a (s)TTI in a serving cell with CRC scrambled with C-RNTI, if PDSCH by means of blind repetition is being received in that (s)TTI in the same serving cell.

Blind/HARQ-less PDSCH repetitions are enabled by RRC configuration. If configured, a single DCI format is used to schedule PDSCH with a given TTI length. There is a field in the DCI that indicates the number of PDSCH transmissions k associated with the DCI, where $k \geq 1$.

For hybrid automatic repeat request (HARQ) for repeated PDSCH transmissions, the UE can report HARQ feedback with the timing given by the last PDSCH repetition.

It is also appreciated that the PDSH repetitions can be included in a downlink control information (DCI).

FIG. 7 is a table illustrating an example mapping **700** of DCI fields for repetitions in accordance with one or more embodiments. The mapping **700** is provided as an example for illustrative purposes and it is appreciated that suitable variations are contemplated.

The mapping **700** is described in reference to a DCI, however it is appreciated that the mapping **700** can be used with other indication techniques, such as signaling and the like.

It is appreciated that a set of repetition levels can follow the NR design/specification where levels of 1 (no repetition), 2, 4 and 8 are supported for sub-frame based PDSCHs. However, this set of repetition levels may not be suitable for sub-slot repetitions because a sub-slot TTI (sTTI) uses 3 sub-slots within a slot and 6 sub-slots within a sub-frame.

A set of repetition levels of 1, 2, 3, and 6 can be used for subslot transmission time interval (sTTI) based PDSCH.

For a slot-based PDSCH, a set of repetition levels can be aligned with the sub-slot since it facilitates resource sharing and the short TTI transmission may not require overall long transmission up to 8 slots, which neglects the benefits of an earlier starting position.

The table of FIG. 7 illustrates the possible or potential mapping **700** for various sub-frame, slot, and/or sub-slot based PDSCH or sPDSCH repetitions. The table includes a DCI bit field, sub-frame and slot or sub-slot.

A DCI bit field of 00 corresponds to a sub-frame of 1 and a slot of 1, which indicates no repetition.

A DCI bit field of 01 indicates a sub-frame repetition of 2 and a slot/sub-slot repetition of 2.

A DCI bit field of 10 indicates a sub-frame repetition of 4 and a slot/sub-slot repetition of 3.

A DCI bit field of 11 indicates a sub-frame repetition of 8 and a slot/sub-slot repetition of 6.

It is also appreciated that other suitable mappings are contemplated.

Additionally, repetition levels can be conveyed by RRC. Thus, a UE-specific RRC configuration can signal a particular set of repetition levels. In one example, a sequence or set of repetition values can include one of the following:

{1,2,4,8}
 {1,2,3,4}
 {1,2,3,6}
 {1,2}
 {1,3}
 {1,4}
 {1,6}
 {1,8}

For this example, if a set of two repetition values is configured to a UE, the DCI field for repetition indication is a 1 bit field; otherwise it is a 2-bit field.

It is also appreciated that repetitions can be performed in consecutive transmission opportunities of the same duration, i.e. sub-frames, slots, and sub-slots subject to a collision (e.g., with changed transmission direction or a dynamic trigger). The repetitions in the conflicted directions in case of conflicts with semi-static configuration of link direction can be postponed to a later opportunity. In case of conflicts with dynamic triggers, the corresponding repetition instance can be dropped, where the (s)PDSCH is assumed to be mapped to the sub-slot/slot/subframe, but not actually transmitted in the DL. Further, the same resource block (RB) allocation for repetitions can be assumed as for an initial transmission without hopping and change of the bandwidth subject to TTI-specific rate-matching procedures.

It is also appreciated that PDSCH repetitions can be un-mapped or not mapped to Multimedia Broadcast multicast service Single Frequency Network (MBSFN) sub-frames. Additionally, repetition levels can be mapped only to DL or special subframes, such as for TDD carriers. For enhanced Interference Mitigation and Traffic Adaptation (eIMTA) PDSCHs, repetitions are dropped when a transmission direction is changed from DL to UL after the UE receives the DL assignment scheduling the PDSCH repetition in corresponding subframes.

It is appreciated that there is a mechanism to enable/disable search space set monitoring in a given sub-slot. Thus, if all candidates are disabled then no SPDSCH scheduling is possible in these sub-slots if no repetitions are enabled. However, scheduling of repetitions can be needed or performed even if no control channel is allocated. Therefore, in another example, SPDSCH can be mapped regardless of whether there is an associated (S)PDCCH monitoring occasion configured in a given slot/sub-slot, when the SPDSCH is scheduled using multiple repetitions.

It is also appreciated that the repetitions can be configured to follow a configured SPDSCH/SPDCCH resource sharing mode. Generally, all combinations of resource sharing modes can be possible between initial transmission and retransmission, however it may not be beneficial to have such flexibility.

FIG. 8 is a table 800 illustrating potential UE behavior for repetitions configured with a resource sharing mode in accordance with one or more embodiments. The table 800 is provided for illustrative purposes and it is appreciated that other suitable behavior is contemplated.

Generally, the UE can perform rate-matching around a whole sPDCCH RB set or does not perform any rate-matching around the whole sPDCCH RB set. The UE

behavior can allow to monitor for sDCI scheduling UL during reception of repetitions, therefore additional configurability for rate-matching mode for repetitions may be required or obtained. Additionally, the rate-matching can be independent on monitoring during repetitions since it may substantially impact overall reliability in case of SPDCCH decoding failure or false positive detection during the repetitions.

Additionally, when a UE discards the DL assignments for C-RNTI received during the repetitions. However, transmission of the assignments itself is typically required to increase chance of UE decoding PDCCH and associated PDSCH. In that case, if received a PDCCH assignment for the already scheduled C-RNTI and is going to discard it, it may perform the rate-matching procedures associated with the discarded DL assignment.

In one example, a UE may not be expected to be configured with rate-matching mode #1, #4 and SPDSCH repetitions in the same time.

Table 800 depicts a mode #, initial transmission (legacy behavior) and repetition. The modes are #1, #2, #3 and #4.

The rate-matching option is indicated dynamically by a 1-bit field in the DCI scheduling SPDSCH.

For example, for mode #1, if the DCI indicates option 1, the UE follows the rate-matching mode associated with the original transmission. Otherwise, if the DCI indicates option 2, the UE does not perform rate matching for the RB set.

For mode #2, the UE rate matches around the whole sPDCCH RB set regardless of the option setting in the DCI. Thus, the UE follows the rate matching mode used for the initial transmission.

Alternatively, the UE follows only one of the options, either Option 1 or Option 2.

It is noted that the table 800 is provided for illustrative purposes and that suitable variations are contemplated. Further, other techniques or handing and configuring rate matching are contemplated.

It is appreciated that utilizing different redundancy versions (RVs) for repetitions or retransmissions can provides coding gains. The gains can be further enhance if the effective code-rate is more than 1/3. Therefore, support of RV cycling across PDSCH repetitions facilitates communications and can be configured.

In one example, the RV cycling sequence used for other cases of LTE, i.e. {0, 2, 3, 1} can be applied for PDSCH and sPDSCH repetitions targeting URLLC use. It is noted that DCI scheduling of the transmission can still contain an RV field which in this case may be used to identify the starting RV in the cycling sequence.

FIG. 9 illustrates examples of an RV fields 900 or values for scheduling transmissions in accordance with one or more embodiments.

The fields indicate a starting index for a RV cycling sequence. For example, RV0 points to a starting index of 0 in the RV cycling sequence. RV1 points to a starting index of 3 in the RV cycling sequence. RV2 points to a starting index of 1 in the RV cycling sequence. RV3 points to a starting index of 2 in the RV cycling sequence.

In another example, the RV sequence for (S)PDSCH repetitions can be semi-statically configured via UE-specific RRC signaling.

Generally, time-dependent PDSCH reception procedures, such as DM-RS scrambling, PDSCH scrambling and the like should or can follow the time index of current (S)PDSCH repetition. Further, the rate-matching procedures associated

with particular TTI (sub-frame, slot, sub-slot) e.g. due to other channels, CSI-RS, etc. should be performed independent of the initial TTI.

In one example, repetitions are performed with modulation order not larger than X, where X can be quadrature phase shift keying (QPSK), quadrature amplitude modulation 16 (QAM16), and/or quadrature amplitude modulation 64 (QAM64) and/or the like. If a modulation restriction is enabled and MCS corresponds to a modulation order larger than X, the UE uses modulation order X for PDSCH mapping procedures assuming the TBS derived from the signaled MCS index.

In another example, a UE can be configured to terminate repetitions at a subframe or slot boundary. In that case, if mapping of repetitions cross the slot or subframe boundary, the UE does not assume that the repetitions which occur after the boundary are transmitted. The HARQ-ACK feedback in is associated with the last actually transmitted (s)PDSCH repetition. Alternatively, the HARQ-ACK feedback timing is defined with respect to the last scheduled (s)PDSCH repetition.

It is appreciated that changes or configurations for downlink (DL) DCI format can be used to signal the repetitions dynamically. First of all, the supported transmission modes are identified. It is noted, that PDSCH repetitions typically lower SE compared with other approaches and facilitate efficient resource usage and scheduling flexibility.

Therefore, it is natural to assume the modes with single code-word are supported with repetitions. The following transmission modes may support repetitions:

TM 1, 2, 3, 4, 6, 9, 10

In one example, in all or a sub-set of the following DCI formats, a bit field indicating the repetition level if repetitions are enabled by the UE-specific RRC configuration is conveyed:

Format 1, 2A, 2, 1B, 2C, 2D

Format 7-1A, 7-1B, 7-1C, 7-1D, 7-1E, 7-1G

In another example, such DCI may only be monitored in UE-specific search space associated with C-RNTI.

Examples can include subject matter such as a method, means for performing acts or blocks of the method, at least one machine-readable medium including instructions that, when performed by a machine cause the machine to perform acts of the method or of an apparatus or system for concurrent communication using multiple communication technologies according to embodiments and examples described herein.

Example 1 is an apparatus for a next Generation NodeB (gNB). The apparatus comprises baseband circuitry and/or application circuitry which includes a radio frequency (RF) interface and one or more processors. The one or more processors are configured to determine a transmission mode for a user equipment (UE) device; dynamically determine a repetition level sequence for a physical downlink shared channel (PDSCH) based on a transmission time interval (TTI) and the transmission mode; generate repetition level signaling for the determined repetition level sequence; and provide the generated repetition level signaling to the RF interface for transmission to the UE device.

Example 2 includes the subject matter of Example 1, including or omitting optional elements, wherein the repetition level sequence is configured within a downlink control information (DCI) field.

Example 3 includes the subject matter of any of Examples 1-2, including or omitting optional elements, wherein the DCI field indicates the determined repetition level sequence based on sub-frame, slot, and/or sub-slot.

Example 4 includes the subject matter of any of Examples 1-3, including or omitting optional elements, wherein the generated repetition level signaling is a physical downlink control channel (PDCCH).

Example 5 includes the subject matter of any of Examples 1-4, including or omitting optional elements, wherein the PDCCH includes a DCI field to indicate the generated repetition level signaling.

Example 6 includes the subject matter of any of Examples 1-5, including or omitting optional elements, wherein the generated repetition level signaling is provided by a radio resource control (RRC) configuration.

Example 7 includes the subject matter of any of Examples 1-6, including or omitting optional elements, wherein the UE device performs a soft combine of the PDCCH and one or more PDSCH transmissions.

Example 8 includes the subject matter of any of Examples 1-7, including or omitting optional elements, wherein the one or more processors are configured to generate an initial PDSCH and one or more PDSCH repetitions for transmission to the UE using the RF interface.

Example 9 includes the subject matter of any of Examples 1-8, including or omitting optional elements, wherein the one or more processors configure initial resource blocks (RBs) for the initial PDSCH transmission and repetition RBs for the one or more PDSCH repetitions.

Example 10 includes the subject matter of any of Examples 1-9, including or omitting optional elements, wherein the one or more processors configure initial rate matching for the initial RBs and repetition rate matching for the repetition RBs based on UE decoding probability.

Example 11 includes the subject matter of any of Examples 1-10, including or omitting optional elements, wherein the repetition rate matching is a same mode as the initial rate matching.

Example 12 includes the subject matter of any of Examples 1-11, including or omitting optional elements, wherein the one or more processors are configured to configure redundancy versions for the one or more PDSCH repetitions.

Example 13 includes the subject matter of any of Examples 1-12, including or omitting optional elements, wherein the one or more processors are configured to identify one or more supported transmission modes that include the determined transmission mode.

Example 14 is an apparatus for a user equipment (UE) device. The apparatus comprises baseband circuitry which includes a radio frequency (RF) interface and one or more processors. The one or more processors are configured to receive a repetition level sequence from the RF interface for one or more physical downlink shared channel (PDSCH) repetitions from a next Generation nodeB (gNB); receive a resource block (RB) configuration from the RF interface for the one or more PDSCH repetitions; handover command message from a source cell; receive a redundancy version (RV) configuration from the RF interface for the one or more PDSCH repetitions; and decode the one or more PDSCH repetitions according to the repetition level sequence, the RB configuration and the RV configuration.

Example 15 includes the subject matter of Example 14, including or omitting optional elements, wherein the repetition level sequence, the RB configuration and the RV configuration are provided within a downlink control information (DCI).

Example 16 includes the subject matter of any of Examples 14-15, including or omitting optional elements,

wherein the one or more processors are further configured to decode the one or more PDSCH repetitions according to a received rate matching.

Example 17 includes the subject matter of any of Examples 14-16, including or omitting optional elements, wherein the one or more processors are configured to soft combine the one or more PDSCH repetitions with a physical downlink control channel (PDCCH).

Example 18 is a one or more computer-readable media. The media has instructions that, when executed, cause a base station, node or next Generation NodeB (gNB) to: determine a transmission mode for a user equipment (UE) device; configure a repetition configuration for the UE device; generate a physical downlink control channel (PDCCH) for the repetition configuration; generate an initial physical downlink shared channel (PDSCH) transmission; and generate one or more PDSCH repetition transmissions according to repetition configuration.

Example 19 includes the subject matter of Example 18, including or omitting optional elements, wherein the repetition configuration is for radio resource controlled (RRC) signaling.

Example 20 includes the subject matter of any of Examples 14-15, including or omitting optional elements, wherein the repetition configuration is within a downlink control information (DCI).

Example 21 includes the subject matter of any of Examples 14-15, including or omitting optional elements, wherein the repetition configuration includes a repetition level sequence, a resource block (RB) allocation, rate matching, and a redundancy version (RV) for the one or more PDSCH repetition transmissions.

Example 22 includes the subject matter of any of Examples 14-15, including or omitting optional elements, wherein the one or more PDSCH repetition transmissions are in consecutive transmission time intervals (TTIs).

Example 23 includes the subject matter of any of Examples 14-15, including or omitting optional elements, wherein the repetition configuration is within a downlink control information (DCI) of a physical downlink control channel (PDCCH) and the DCI includes a UE specific search space that indicates a number of PDSCH repetitions.

Example 24 includes the subject matter of any of Examples 14-15, including or omitting optional elements, wherein the instructions, when executed, further cause the gNB to apply a modulation restriction, wherein the modulation restriction is selected from a group comprising quadrature phase shift keying (QPSK), quadrature amplitude modulation 16 (QAM16), and/or quadrature amplitude modulation 64 (QAM64).

As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

As it employed in the subject specification, the term "processor" can refer to substantially any computing processing unit or device including, but not limited to including, single-core processors; single-processors with software multithread execution capability; multi-core processors; multi-

core processors with software multithread execution capability; multi-core processors with hardware multithread technology; parallel platforms; and parallel platforms with distributed shared memory. Additionally, a processor can refer to an integrated circuit, an application specific integrated circuit, a digital signal processor, a field programmable gate array, a programmable logic controller, a complex programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions and/or processes described herein. Processors can exploit nano-scale architectures such as, but not limited to, molecular and quantum-dot based transistors, switches and gates, in order to optimize space usage or enhance performance of mobile devices. A processor may also be implemented as a combination of computing processing units.

In the subject specification, terms such as "store," "data store," "data storage," "database," and substantially any other information storage component relevant to operation and functionality of a component and/or process, refer to "memory components," or entities embodied in a "memory," or components including the memory. It is noted that the memory components described herein can be either volatile memory or nonvolatile memory, or can include both volatile and nonvolatile memory.

By way of illustration, and not limitation, nonvolatile memory, for example, can be included in a memory, nonvolatile memory (see below), disk storage (see below), and memory storage (see below). Further, nonvolatile memory can be included in read only memory, programmable read only memory, electrically programmable read only memory, electrically erasable programmable read only memory, or flash memory. Volatile memory can include random access memory, which acts as external cache memory.

It is to be understood that aspects described herein can be implemented by hardware, software, firmware, or any combination thereof. When implemented in software, functions can be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media or a computer readable storage device can be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or other tangible and/or non-transitory medium, that can be used to carry or store desired information or executable instructions. Also, any connection is properly termed a computer-readable medium. For example, if software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

Various illustrative logics, logical blocks, modules, and circuits described in connection with aspects disclosed

herein can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform functions described herein. A general-purpose processor can be a microprocessor, but, in the alternative, processor can be any conventional processor, controller, microcontroller, or state machine. A processor can also be implemented as a combination of computing devices, for example, a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Additionally, at least one processor can comprise one or more modules operable to perform one or more of the s and/or actions described herein.

For a software implementation, techniques described herein can be implemented with modules (e.g., procedures, functions, and so on) that perform functions described herein. Software codes can be stored in memory units and executed by processors. Memory unit can be implemented within processor or external to processor, in which case memory unit can be communicatively coupled to processor through various means as is known in the art. Further, at least one processor can include one or more modules operable to perform functions described herein.

Techniques described herein can be used for various wireless communication systems such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA and other systems. The terms “system” and “network” are often used interchangeably. A CDMA system can implement a radio technology such as Universal Terrestrial Radio Access (UTRA), CDMA1800, etc. UTRA includes Wideband-CDMA (W-CDMA) and other variants of CDMA. Further, CDMA1800 covers IS-1800, IS-95 and IS-856 standards. A TDMA system can implement a radio technology such as Global System for Mobile Communications (GSM). An OFDMA system can implement a radio technology such as Evolved UTRA (E-UTRA), Ultra Mobile Broadband (UMB), IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.18, Flash-OFDM, etc. UTRA and E-UTRA are part of Universal Mobile Telecommunication System (UMTS). 3GPP Long Term Evolution (LTE) is a release of UMTS that uses E-UTRA, which employs OFDMA on downlink and SC-FDMA on uplink. UTRA, E-UTRA, UMTS, LTE and GSM are described in documents from an organization named “3rd Generation Partnership Project” (3GPP). Additionally, CDMA1800 and UMB are described in documents from an organization named “3rd Generation Partnership Project 2” (3GPP2). Further, such wireless communication systems can additionally include peer-to-peer (e.g., mobile-to-mobile) ad hoc network systems often using unpaired unlicensed spectrums, 802.xx wireless LAN, BLUETOOTH and any other short- or long-range, wireless communication techniques.

Single carrier frequency division multiple access (SC-FDMA), which utilizes single carrier modulation and frequency domain equalization is a technique that can be utilized with the disclosed aspects. SC-FDMA has similar performance and essentially a similar overall complexity as those of OFDMA system. SC-FDMA signal has lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure. SC-FDMA can be utilized in uplink communications where lower PAPR can benefit a mobile terminal in terms of transmit power efficiency.

Moreover, various aspects or features described herein can be implemented as a method, apparatus, or article of

manufacture using standard programming and/or engineering techniques. The term “article of manufacture” as used herein is intended to encompass a computer program accessible from any computer-readable device, carrier, or media. For example, computer-readable media can include but are not limited to magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips, etc.), optical disks (e.g., compact disk (CD), digital versatile disk (DVD), etc.), smart cards, and flash memory devices (e.g., EPROM, card, stick, key drive, etc.). Additionally, various storage media described herein can represent one or more devices and/or other machine-readable media for storing information. The term “machine-readable medium” can include, without being limited to, wireless channels and various other media capable of storing, containing, and/or carrying instruction(s) and/or data. Additionally, a computer program product can include a computer readable medium having one or more instructions or codes operable to cause a computer to perform functions described herein.

Communications media embody computer-readable instructions, data structures, program modules or other structured or unstructured data in a data signal such as a modulated data signal, e.g., a carrier wave or other transport mechanism, and includes any information delivery or transport media. The term “modulated data signal” or signals refers to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in one or more signals. By way of example, and not limitation, communication media include wired media, such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media.

Further, the actions of a method or algorithm described in connection with aspects disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or a combination thereof. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium can be coupled to processor, such that processor can read information from, and write information to, storage medium. In the alternative, storage medium can be integral to processor. Further, in some aspects, processor and storage medium can reside in an ASIC. Additionally, ASIC can reside in a user terminal. In the alternative, processor and storage medium can reside as discrete components in a user terminal. Additionally, in some aspects, the s and/or actions of a method or algorithm can reside as one or any combination or set of codes and/or instructions on a machine-readable medium and/or computer readable medium, which can be incorporated into a computer program product.

The above description of illustrated embodiments of the subject disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are possible that are considered within the scope of such embodiments and examples, as those skilled in the relevant art can recognize.

In this regard, while the disclosed subject matter has been described in connection with various embodiments and corresponding Figures, where applicable, it is to be understood that other similar embodiments can be used or modifications and additions can be made to the described embodiments for performing the same, similar, alternative, or substitute function of the disclosed subject matter without

deviating therefrom. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

In particular regard to the various functions performed by the above described components (assemblies, devices, circuits, systems, etc.), the terms (including a reference to a “means”) used to describe such components are intended to correspond, unless otherwise indicated, to any component or structure which performs the specified function of the described component (e.g., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations of the disclosure. In addition, while a particular feature may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

What is claimed is:

1. An apparatus for a base station, comprising baseband circuitry having:
 - a radio frequency (RF) interface; and
 - one or more processors configured to:
 - dynamically determine a repetition configuration for a physical downlink shared channel (PDSCH), wherein the repetition configuration includes a number of PDSCH repetitions, a cycling sequence of redundancy versions (RVs), and an indication which RV of the cycling sequence of RVs to employ with an initial PDSCH;
 - generate repetition level signaling for the determined repetition configuration, wherein the repetition level signaling comprises the initial PDSCH and one or

more PDSCH repetitions for transmission to a user equipment (UE) using the RF interface, the cycling sequence of RVs for the initial PDSCH and the one or more PDSCH repetitions, and an RV field that indicates a starting index of the cycling sequence of RVs,

wherein the one or more processors configure initial resource blocks (RBs) for the initial PDSCH and repetition RBs for the one or more PDSCH repetitions, and wherein the one or more processors configure initial rate matching for the initial RBs and repetition rate matching for the repetition RBs based on UE decoding probability; and

provide the generated repetition level signaling to the RF interface for transmission to the UE.

2. The apparatus of claim 1, wherein the repetition configuration is configured within a downlink control information (DCI) field.
3. The apparatus of claim 2, wherein the DCI field indicates the determined repetition configuration based on sub-frame, slot, and/or subslot.
4. The apparatus of claim 1, wherein the generated repetition level signaling is a physical downlink control channel (PDCCH).
5. The apparatus of claim 4, wherein the PDCCH includes a DCI field to indicate the generated repetition level signaling.
6. The apparatus of claim 1, wherein the generated repetition level signaling is provided by a radio resource control (RRC) configuration.
7. The apparatus of claim 1, wherein the repetition rate matching is a same mode as the initial rate matching.

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